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Main author: Begonya Otal (BDIGITAL), Rupert Ortner (GTEC), Ruben Real (UNI WUE), M. J. van Steensel (UMCU), Gert Kristo (UMCU), Johannes Höhne (TUB), Mannes Poel (UT)

Other authors: Sandra Veser (EKUT), Eloy Opisso (FPING), Patric Salomon (EMNT), Maria Laura Blefari (EPFL), Clemens Brunner (TUG), Boris Reuderink (UT), Floriana Pichiorri (FSL), Francesca Schettini (FSL), Christoph Guger (GTEC), Felip Miralles (BDIGITAL), Gernot Müller-Putz (TUG)

Abstract: This deliverable describes the evolution of BCI and BCI-related industry stakeholders towards 2020 focusing on task 3.2 related issues. We evaluate emerging tools, technologies, and synergy fields with regard to their potential transfer to industry and their market impact. Further, current and new target user groups, BCI application scenarios and the need for user involvement in the development process are highlighted. Finally, we estimate principles which are likely to guide future opportunities for interfacing with industry stakeholders, target end users, potential competitors, collaborators, and some of their interrelations.

Keywords: Brain-Computer Interface, BCI, Brain-Neural Computer Interaction, BNCI, Human-Computer Interaction, HCI, Roadmap, End User, Primary User, Market assessment, Market impact, Market value, Market growth, Future opportunities

[1] Public
[2] Restricted to other program participants
[3] Restricted to a group specified by the consortium
[4] Confidential, only for members of the consortium

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1 Introduction and objectives

BCI research is rapidly maturing. The previous roadmap from the Future BNCI CSA (see Future BNCI) showed that new groups from different backgrounds had begun sharing ideas, and new directions, and that new target user groups were emerging. However, because of this rapid progress, several problems have surfaced. Primarily, these are related to the lack of agreement on the most promising future directions. Integrating BCIs with other interaction paradigms in synergy fields and other emerging technologies entails working with new groups of people. However, these efforts lack stringent coordination, which has made it difficult to objectively assess which technologies (and new combinations thereof) are promising. Companies, policy makers, medical decision makers, patients, and other groups without a BCI background may find it especially difficult to identify the most promising BCI market applications, funding opportunities, or treatment options.

This deliverable describes the evolution of the BCI industry towards 2020 (see description of task 3.2 in BNCI Horizon 2020 DoW). It summarizes results from WP2 (Research), WP4 (End Users) and WP3 (*BNCI Industry Ecosystem, deliverable* D3.1). Here, we evaluate emerging tools, technologies, and possibilities for synergies with regard to their potential transfer to industry and their impact on the market. Further, current and new target user groups, BCI application scenarios and the need for user involvement in the development process are highlighted. Finally, we estimate principles which are likely to guide future opportunities for interfacing with industry stakeholders, target end users, potential competitors, collaborators, and some of their interrelations.

2 Current and emerging BCI tools and techniques

Deliverables D2.1 and D2.2 (WP2) identified the following current and emerging tools and techniques in BCI research and applications. We also characterise other not necessarily competing BCI-related methodologies that may give rise to potential hybrid-BCI opportunities in identified synergies in the near future (see section 4 as well).

2.1 Non-invasive BCIs and BCI paradigms

All non-invasive BCI systems rely on sensors which record brain activity from outside the brain. Although there have been recent advancements in the development of neuroimaging technologies such as fNIRS and fMRI, most non-invasive BCI systems are based on EEG signals (Nicolas-Alonso and Gomez-Gil, 2012; Hwang et al., 2013). Novel EEG systems have been introduced, striving for a more practical technical setup. Such novel systems utilized electrodes which could be used without conductive gel (Fonseca et al., 2007; Shi et al., 2012; Volosyak et al. 2010). Moreover, wireless EEG systems as well as less expensive and less bulky systems have become commercially available (Nicolas-Alonso and Gomez-Gil, 2012).

BCI paradigms can be classified into exogenous and endogenous systems, depending on whether external stimulation is required (Wolpaw and Wolpaw, 2012). Exogenous BCIs (e.g. based on Event-Related Potentials (ERPs) or Steady-State Evoked Potentials (SSEP)) often use the visual modality to evoke brain responses, but auditory or somatosensory stimulation can be used as well. Compared to endogenous BCIs, they require less training, fewer sensors, and show a higher information throughput. However, the users need to permanently direct attention towards those stimuli, which might be tiring and inconvenient for other simultaneous tasks due to the occupation of sensory capacity (Gao et al., 2013). Driven by voluntarily controlled brain rhythms, endogenous BCIs do not need a stimulation device. Moreover, they typically offer a continuous instead of discrete output (McFarland et al., 2010).

In general, BCI technology has been proposed as a tool for various purposes - from communication (Kübler et al., 2001a; Scherer et al., 2004; Blankertz et al., 2007; Nijholt, 2009; Schreuder et al., 2010; Treder and Blankertz, 2010; Höhne et al., 2011; Riccio et al., 2011; Treder et al., 2011; Aloise et al., 2012; Höhne et al., 2012; Riccio et al., 2012; Müller-Putz et al., 2013) to entertainment (Krepki et al., 2007; Millán et al., 2008; Scherer et al., 2012; Leeb et al., 2013; van de Laar et al., 2013) and rehabilitation (Daly et al., 2008; Silvoni, 2011; Mattia et al., 2012). While numerous non-invasive BCI paradigms have been tested and optimized with healthy participants, the number of experiments in individuals with functional deficits or patients is rather limited (Kübler, 2013). Thus, it is not yet clear to what extent the achievements with healthy users can be transferred to this last group.

2.2 Issues on invasive BCIs

The most widely applied invasive techniques for BCIs are multi electrode arrays (MEAs) and electrocorticography (ECoG). MEAs are arrays of tens to hundreds short needles that are inserted into the cortical tissue. Because of the unique possibility to record single units from many electrodes simultaneously, MEA BCIs mainly focus on maximizing the number of degrees of freedom, e.g. in the control of a computer cursor or robotic arm (Georgopoulos et al., 1982; Hochberg et al., 2006). Most recent advancements are related to optimizing performance (e.g. by new algorithms or combining single unit data with LFPs), as well as biocompatibility and long-term stability of the signals (e.g. using biocompatible coatings) (Lee et al., 2013; Gilja et al., 2011; Lu et al., 2012). In addition, several groups are working on wireless solutions to improve safety (Sharma et al., 2012; Chestek et al., 2009; Yin et al., 2013; Schwarz et al., 2013), and different types of feedback (besides visual), such as electrical stimulation of the muscles to restore grasping (Shih et al., 2012; Lu et al., 2012), or electrical stimulation of the cortex to induce somatosensory perception (Lee et al., 2013; Schultz and Kuiken, 2011). ECoG measures fields generated from large groups of neurons, using cortical surface electrodes. Current ECoG-BCI research mainly aims at replacing lost motor function, using consciously generated changes in signals of isolated brain regions or ERPs. Control over a cursor (1-3 dimensions), prosthetic hand, and speller has been demonstrated, and is quickly obtained (Shih et al., 2012). Recent developments are associated with choosing and non-invasively pre-localizing optimal brain regions for control, designing wireless solutions (Charvet et al., 2013; Matsushita et al., 2013), investigating the possibilities of epidural recordings (Moran 2010; Ritaccio et al., 2011; Torres Valderrama et al., 2010) and maximizing the number of degrees of freedom, for example with new high, resolution grids (Ritaccio et al, 2011; Wang et al., 2008).

2.3 Data processing tools

Recorded neuroimaging data are a superposition of the signals of interest with a plethora of other signals - from the brain, from muscles, and from non-biological artifacts. Furthermore, the huge variability of brain activity between persons makes the real-time analysis of brain signals a challenge. Therefore, state-of-the-art BCI systems use adaptive signal processing and machine learning algorithms to extract specific information from the brain signals. These techniques rely on a statistical analysis of calibration data to optimize classification models. Research on BCI data processing focuses on several topics: (I) improving classification performance (Blankertz et al., 2011; Malik et al., 2011), (II) integrating several streams of data (Leeb et al., 2010, Müller-Putz et al., 2011) - i.e. hybrid BCI, (III) facilitating applicability by algorithms that enable a BCI to be operated with less/no calibration data (Kindermans et al., 2014), or in a noisy and non-stationary environment (Samek et al., 2012) and (IV) enhancing interpretability of processing tools (Haufe et al, 2013) in order to validate underlying neurophysiological hypotheses (Lemm et al., 2011).

2.4 Other BCI-related techniques

Apart from the current invasive and non-invasive BCI methods described above, there are other techniques used for similar purposes (e.g. rehabilitation methods) that can be related to

BCIs, for example functional electrical stimulation (FES), and non-invasive brain stimulation techniques, including repetitive transcranial magnetic stimulation (rTMS) and transcranial direct current stimulation (tDCS).

FES is a technique mainly used for restoration and rehabilitation in neurological disorders. The major areas of application include assisted walking in paraplegia, cases of spinal cord injury and in hemiplegic gait training. Other areas where FES has been used with success include quadriplegia, cerebral palsy, urinary incontinence, vestibular dysfunctions and sexual dysfunctions. Electrical stimulation of the vagus nerve has been shown capable of reducing seizure frequency in epilepsy. The possible benefits of FES could be manyfold: improvement of muscle strength, increase of muscle stretch and hence reduction of spasticity. Furthermore it elicits cortical reorganization and neuronal plasticity, which plays a major role in rehabilitation of stroke patients. FES is not competing to BCIs, but instead could be combined with BCIs to strengthen the expected results. For example, BCIs can be used to control FES-based orthoses, replacing the natural central nervous pathways towards the muscles (Pfurtscheller et al., 2003; Pfurtscheller et al., 2005; Kreilinger et al., 2013; Looned et al., 2014). Also, BCIs and FES can be used for rehabilitation of motor functions after stroke (Meng et al., 2008; Do et al., 2011; Irimia et al., 2013).

Recently, rTMS and tDCS have shown promise as potential approaches for enhancing post-stroke recovery, in both motor (Le et al., 2014) and language (Elsner et al., 2013; Tsai et al., 2014; Wong and Tsang 2013) rehabilitation. A number of research studies employing these techniques, especially rTMS, have reported lasting improvement in specific language functioning patients with chronic post-stroke aphasia. In addition to behavioural improvement, evidence of induced neuroplasticity has further validated the efficacy of these interventions. However, application of therapeutic non-invasive brain stimulation techniques within few days after stroke i.e., in sub-acute and acute phase, is still in its infancy (Shah et al., 2013). In relation to the BCI context, some new tools are emerging, such as the integration of multi-channel brain stimulation electrodes with a fully-fledged wireless EEG that enables dual use of electrodes for stimulation and EEG monitoring on same or near sites[5].

3 Towards future end users groups - key opportunities

Deliverable D4.1 identified target end user groups and their relation to BCI application scenarios. Their potential industry adoption relies heavily on a user-centered design (UCD) approach (c.f., standardization in ISO-DIS-9241-210), in which the end user influences the development process of a final product. Generally, this goal is achieved, firstly, by analysing user needs and specifying user requirements, which guide implementation during the design and development phases; and, secondly, by testing and evaluating pilot products (and prototypes) against the previous specified requirements after several iterative development phases – i.e. usability tests. In the following, we summarise the three user-types (primary, secondary and tertiary users) and their potential relations to BCI application scenarios (see table in Annex 1 for details). We also introduce a new section that establishes the path towards potential future end user groups and their relation to the BCI applications scenarios in flourishing key identified opportunities.

3.1 Primary users

In the BCI field, primary users (or end users) are those who will directly benefit from a BCI market solution in one of the identified BCI application scenarios (see Table 2 and Figure 1). This means that a BCI system can be used to either ***replace***, ***restore***, ***enhance***, ***supplement*** or ***improve*** a primary user's natural central nervous system (CNS) output to change or control the ongoing interaction between his or her CNS and their environment (Wolpaw and Wolpaw,

[5] http://www.neuroelectrics.com/starstim

2012). In addition, BCI technology can also be used for basic science, such as exploring brain functions and their interactions. Thus, a new ***research*** application scenario was included. Regarding these BCI application scenarios, we can further differentiate between primary users *with functional deficits* and primary users *without functional deficits* (here also referred as healthy users).

3.1.1 End users with functional deficits

Primary users with functional deficits are most closely related to the ***replace***, ***restore*** and ***improve*** BCI application scenarios. A BCI application in the replace scenario can be a BCI communication tool that enables a person – who can no longer speak – to use a speech synthesizer. Likewise, another person – who has lost limb control – might use a BCI to steer a motorized wheelchair. Some of these BCI solutions can also be classified as assistive technologies (AT). People using a BCI in the restore application scenario are those who may benefit from FES to stimulate peripheral nerves along paralysed muscles and restore natural motor functions, or use BCI-controlled prostheses, for the same purpose. People who use BCI applications as rehabilitation tools in the improve scenario will be those who relearn functional motor movements, or get a BCI to improve functional language deficits after a stroke event.

3.1.2 End users without functional deficits (healthy users)

Healthy primary users are mostly found in the ***enhance***, ***supplement*** and ***research*** application scenarios (see Annex 1). Generally, these primary users would use a BCI tool to enhance their performance in demanding tasks, or just to have fun during gaming. Similarly, they could supplement their natural CNS output, e.g. by using a BCI controlled third arm, while performing a specific task in adverse environments. The same methodologies could also be used to understand normal and abnormal brain functioning in the research application scenario. Note that users with functional deficits can also take advantage of the enhance and supplement application scenarios in a similar way.

3.2 Secondary and tertiary users

Secondary users are those who will use the BCI product occasionally, or who use it through an intermediary, while tertiary users (professional users or other stakeholders) are those who will be affected by the use of the BCI product or make decision about its purchase. Examples of tertiary users are insurance companies, public health systems or even manufacturers. Depending on the BCI application scenario, professional users may fall under the secondary or tertiary user category (see D4.1; Annex 1). That is, secondary users (non-professional or professional) in the aforementioned BCI application scenarios are mainly caregivers, relatives, researchers, therapists performing BCI tests, and other people, who by interacting with primary users can indirectly benefit from a BCI system, i.e. generally improving a service performance. Professional tertiary users can be manifold, ranging from industry manufactures to medical doctors, who may be directly affected by the use of a BCI market solution, i.e. making real profit (financially speaking).

3.3 Future end users groups in key BCI opportunities

Most of the BCI literature addressing usability issues refers to the ***replace*** application scenario (see D4.1), which aims at replacing lost functions in primary users with functional deficits. Only some studies, mostly relating to the ***enhance*** scenario, refer to primary users without functional deficits, mainly in areas such as gaming, human-computer interaction (HCI) design, or workload monitoring. In this section, we take a human factor based approach (Boff, 2006), identifying future user groups and future application scenarios by first examining the unique abilities BCI technology offers (Blankertz et al. 2010). This will allow us to identify conditions, under which this technology is likely to be of benefit, and, consequently, to identify new potential users[6].

[6] To this end, additional information was collected, including information on use of BCI technology for military applications. This was done, because the military represents a high-risk environment, and, is, thus, suited for identifying potential future uses

According to Lance et al. (2012), BCI technologies offer the following key opportunities, which are not readily available using other technology (Table 1):

Table 1 – Key opportunities provided by knowledge of users' brain activity (Lance et al. 2012).

- The human brain holds more information than can be assessed using behaviour alone. Leveraging this potential would allow development of new human-computer interaction capabilities.
- Human brain processes show high inter- and intra-individual variability, with a strong correspondence to behavioural variability. Information about brain processes would thus allow optimizing applications to the user's mental state.
- Knowledge of the brain's ability for plasticity allows tailoring of training, rehabilitation, and learning.

In this regard, BCIs hold the potential of not only designing machines to match human capabilities, but also to amplify human capabilities to match a given task (Boff, 2006). Lance et al. (2012) identified six high-level application areas for future BCI use. Thus, BCIs may be used for 1) **direct control**, or 2) **indirect control**, 3) **communication**, 4) **brain-process modification**, 5) **mental state detection**, and 6) **opportunistic BCIs**. Thus, a natural way to search for potentially new users of BCI technology is in environments where human capabilities to work, or, more generally, to perform any activity they would like to do, are constantly stretched. This view is closely mirrored in the Wolpaw & Wolpaw (2012) scenarios, which either concentrate on users with limiting functional disabilities (replace, restore, improve) or users who would like to possess additional capabilities (enhance, supplement). For example, airline safety might profit from monitoring workload and attention of pilots, security sensitive areas might want to use BCI-based biometrics, and the entertainment industry might to use BCI technology for optimal immersion. An extensive description of potential user groups is presented in section 4.1 (Synergy fields for future opportunities).

In terms of opportunistic BCIs, Lance et al. (2012) highlighted that for the foreseeable future BCIs are likely to remain task-oriented, i.e. their maximum advantage lies in areas where they provide access to data, which would otherwise be inaccessible. However, once BCI technology has permeated everyday life, new opportunities will arise in areas hard to foresee at the moment. For example, while using a BCI for room temperature control would not be feasible at the moment, it might become an option once the necessary infrastructure is available. Similar to the spreading of health-related mobile phones apps, health-BCIs might become available in the future, for example to indicate an impending migraine attack. Further opportunities where BCI technology might impact on other fields are explored in section 4.1 (Synergy fields for future opportunities).

3.4 End users in the BCI development process

As previously mentioned, User-Centered Design (UCD) focuses on the concept of usability, i.e. "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". Translated to the BCI context, UCD is essentially the process in which the needs, likes, dislikes, and limitations of BCI end users (especially primary and secondary users, but also tertiary users) are given extensive attention to, at each stage of the design, development and testing processes. That is, the UCD approach is directly linked to the user needs and functional requirement specifications, and also to the usability testing of pilot products (and prototypes) against the previous specified requirements. Based on UCD principles, D4.1 provided a methodology for the identification and classification (stratification) of potential users. UCD is standardized in

for personnel working in this condition. Note, however, that military applications are not the primary focus of this section, as was agreed upon during the Hallstatt retreat.

the ISO 9241-210. There are four linked UCD activities that shall take place during the design of any interactive system (ISO-9241-210, 2008, Bevan, 2009). These are,

1) Understand and specify the context of use
2) Specify the user requirements
3) Produce design solutions
4) Evaluate

As UCD is a key aspect for transferring BCI technology towards the industry and for long-term end user adoption, there are already efforts introducing the UCD approach into the BCI research process, (see e.g. Zickler et al. (2013). If BCI technology is introduced into the market either as a medical device or as a medical system (i.e. BCI solutions in the ***replace***, ***restore***, ***improve*** applications scenarios), medical certification will also be required and will have to be followed during the aforementioned design, development and evaluation processes in combination with the UCD approach. In relation to the BCI development process, the most common concerns from industry stakeholders are that BCI devices have to be *robust* and highly *reliable*, since BCI applications need to work within everyday life and in a wide range of different environments. This means, BCI devices must be robust against artefacts caused by external disturbances, movements of primary users, or noise and interferences from other devices in the vicinity. Reliability is also a special concern due to the fact that the sponsor (usually an industry stakeholder) needs to demonstrate the benefits of a BCI-based solution over some alternative methods. Besides, the efficacy of the BCI device requires to be acknowledged in front of other competing techniques (especially in the medical domain). Apart from that, BCI EEG-based devices need to be simple and user-friendly – especially for primary and secondary users –, and the electrodes should to be easy to apply. In this sense, a common bottleneck for BCI devices is often the need of gel or water solution for the electrodes to increase the system accuracy and reliability, requiring – in this case – also a third party to help in the procedure prior to start using the device. Note that most of this input was gathered from specific responses of those BCI-related industrial stakeholders, who answered our BNCI Industry Questionnaire (see D3.1).

4 Future opportunities, industry transfer and market impact

Following our previous analysis in section 3.3, we evaluate here several synergy fields and related key BCI market applications extracted from the results reported in WP2, WP3 and WP4. Further, we pursue to portray a qualitative estimation regarding their relative market value, and relative market growth by 2020 taking into account the evaluations, interpretation and experience of BNCI Horizon 2020 consortia experts.

4.1 Synergy fields for future opportunities

Several industry stakeholders are already using brain-controlled devices shown to be relevant in improving efficacy and efficiency. As ongoing research looks promising, the impact of BCIs on our society is expected to increase in the near future thanks to new emerging opportunities in potential synergy fields (identified in D3.1 – BNCI Industry Ecosystem Database, and D2.2). In this sense, the EU-funded project *Brainflight*[7] showed new opportunities with the **aerospace** sector by an ambitious project investigating the feasibility of flying a brain-controlled aircraft, which would reduce the workload of pilots and increase safety. Likewise, synergies between the **automotive** industry and BCI comprise cars that claim to be geared, steered or provide feedback by using brain-controlled systems like BrainDriver, or iBrain. Examples of potential opportunities that could most benefit the **health care** or **medtech** industry are brain-controlled bionic legs and arms, or futuristic

[7] http://www.fp7-brainflight.eu/

computerized bladders. BCIs may also aid treatment of neurodegenerative diseases in the recovery of lost cerebral functions. In 2009, FDA approved a second clinical trial to implant the BrainGate technology into severely disabled patients, and g.tec recently introduced its mindBEAGLE platform, resulting from the EU-funded project DECODER[8].

Further, BCI devices have a number of growing opportunities in the **entertainment** sector. The industry of **education** is one of the major targets for Open Source (Puzzlebox Orbit) or commercial (MindWave Education) brain-controlled devices. These games claim to monitor the attention levels of students performing a task. Other companies in the **entertainment** sector are developing BCI-based games, which let you manipulate targets just by concentrating on them (NeuroBoy, Mindflex and the Star Wars Force Trainer). Games like Focus Pocus can be played on a PC simultaneously by multiple players, which is a new trend in the gaming industry. One of the ideas behind BCI in games is that the shortcomings of the BCI can be turned in to challenges. The industry of **music** will release a device called NEURO TURNTABLE (by Neurowear), which plays music only when the user is concentrated. The **wellness** industry may benefit from BCI tools by devices like MUSE (Interaxon), which guides you to relax or focus before or after you perform a mentally challenging task, and which could be used for meditation. Moreover, BCIs may allow the **marketing** sector to tailor **advertising** to an individual, based on mood, emotional state and cognitive analysis. If successful, this could be incorporated in any device that allows for neurofeedback, including brain-controlled games and mobiles of companies such as Personal Neuro Devices, Neurosky, Nielsen, and Neurofocus.

Large multinational companies in the **technology** sector are likely willing to build joint ventures with those BCI stakeholders offering the most promising BCI solutions. Apparel and accessories companies are bringing out brain-controlled clothing and gadgets, such as Neurowear`s Necomimi and Shippo, which would communicate individual moods. Other industry stakeholders in the BCI sector have produced systems (Epoc, intendiX, Brainfingers, BrainGate) for brain–control of laptops and PC`s that may be benefitial for the **computer** industry. Potential synergies with the **telecommunication** industry are exemplified by Neurosky`s MindWave mobile headset compatible with Apple iOS products, and Android smartphones and tablets. Notably, despite the claims of the companies marketing these products, for most of these systems it is not clear if control is based on neuronal (EEG) or muscle (EMG) activity. Following the same line, synergies between BCIs and **assistive technologies (AT)** are progressing rapidly as shown by the brain-controlled Darpa`s Prosthetic Arm. We recently saw the success of the EU-funded projects *MindWalker*[9], *WalkAgain*[10], and *TOBI*[11]. Similarly, other EU-funded projects such as *BrainAble*[12] and *BackHome*[13] relate **AT** and **domotics** with BCIs for smart home control aiming at improving autonomy in persons with functional deficits.

Additionally, the **defence** industry (e.g. Defense Advanced Research Projects Agency-DARPA) is interested in mind-control of drones, weapons, aircraft, or robotic devices, or manipulation of the brain to enhance war-fighting capabilities, maintain mental acuity and reduce the effects of traumatic brain injury. Last but not least, BCI's can dramatically change **livestock farming** by providing access the animal's mental states, such as stress or fear levels, thereby helping to optimize the industry, and generally to improve animal welfare. This could indirectly influence human nutrition and health in the long-term.

[8] http://www.decoderproject.eu/
[9] https://mindwalker-project.eu/
[10] http://virtualreality.duke.edu/project/walk-again-project/
[11] http://www.tobi-project.eu/
[12] http://www.brainable.org/
[13] http://www.backhome-fp7.eu/

4.2 Key BCI market applications

For decades, BCIs have been used for restoring the communication and mobility of persons with functional deficits through applications such as spellers, web browsers, and wheelchair controls (Gürkök and Nijholt 2012). In parallel to advances in computational intelligence and the production of consumer BCI products, BCIs have recently started to be considered as alternative modalities in HCI. One of the popular topics in HCI is multimodal interaction (MMI), which deals with combining multiple modalities in order to provide powerful, flexible, adaptable, and natural interfaces. With the emerging portable and usable signal acquisition hardware as well as robust data processing and artefact removal techniques, BCIs have started to be considered as an HCI modality for healthy users, as well. Some potential non-medical BCI applications include games, attention monitors and interfaces to smart mobile devices. A typical use case would be the interaction between a user and smart glasses (e.g. Google glass). Currently, the user can interact with the smart glasses using speech, gestures, or buttons. A drawback of these approaches is that the need to talk to the system might compromise privacy, whereas the use of a future BCI system is comparably unobtrusive. However, such as BCI would need to be robust against interference, non-visible or aesthetically pleasing. An example could be small in-ear sensors or sensors integrated in a baseball cap or hair extensions. Even piercing-sensors might be appealing to some determined group of end users. Another interesting direction is the use of BCI's in (serious) games. One of the ideas behind BCI in games is that the shortcomings of the BCI can be turned in to challenges (Nijholt et al 2009). Most BCI games of today are developed for research purposes as a proof-of-principle or are adaptations of existing games where traditional input mechanisms, e.g. a key press, are replaced by BCI.

In order to further assess future BCI opportunities and evaluate their potential market impact, Table 2 presents the main *subcategories* (here BCI *application groups*) identified in our BNCI Industry Ecosystem Database (see D3.1- the *application category*). Table 2 – in relation to the analysis summarised in Table 1 – intends to classify different BCI and BCI-related stakeholders according to their potential target market applications or market segments. Within each application group, we list potential key BCI-related market applications in relation to the identified synergy fields introduced before.

Table 2 – Application groups and potential key BCI market applications (in relation to synergy fields and sectors)*

Application groups	Key BCI-related market applications
Communication & Control	affective computing, interface to smartphones, multimodal PC interaction, apparel and accessories (**technology sector**)*
Health & Neurofeedback	prevention, diagnosis, therapy, monitoring, cognitive and motor rehabilitation , addiction disorders, wellness, nutrition (**medtech & rehab & robotic sector)***
AT & Smart home control	ambience intelligence, domotics, elderly care, geriatric hospices (**technology sector**)*
Safety & Security	public transport (**automotive and aerospace sectors**)*, fire brigade, police, process controls, banking security, agriculture
Entertainment & Gaming	educational games, serious games, cinema, art, sports, meditation techniques (e.g. yoga, tai chi) (**entertainment sector**)*
Neuromarketing & Finance	market research, decision-making studies and support (**marketing sector**)*, neuroeconomics, stockbrokers
R&D	real-time analysis, signal acquisition, signal processing, output devices, BCI-hybrid interfaces, artificial intelligence & machine learning

* Relates to D3.1 identified synergy sectors (i.e. industry stakeholders in potential BCI-related sectors).

4.3 Market applications in relation to BCI application scenarios

Based on the BCI definition from Wolpaw and Wolpaw (2012) and the related application scenarios already introduced in previous deliverables (see D3.1), Figure 1 aims at depicting a tentative match among these application scenarios and the application groups identified above (comprising the key market BCI applications illustrated in Table 2). In this sense, the ***replace*** application scenario would include *Communication & Control,* and also *AT & Smart home control* market applications. For this aim, a BCI device replaces the natural output that has been lost as a result of injury or disease (e.g. to provide communication, or motorized wheelchair control, in-house light control, or bed position control). Following Figure 1, *Health & Neurofeedback* applications overlap also the ***replace*** scenario - i.e. BCI applications specifically addressed to in-hospital patients with disorders of consciousness. Nevertheless, *Health & Neurofeedback* market applications most directly relate to both the ***restore*** and ***improve*** application scenarios. In the former, a BCI restores lost natural output (e.g. a person using a BCI to stimulate a paralyzed muscle via implanted electrodes to move the limbs). In the latter, a BCI device aims at improving natural CNS output. (e.g. a person using a BCI to detect and enhance signals from a damaged cortical area in order to rehabilitate functions that have been impaired).

The widest scope within the identified key BCI market applications can be found in the ***enhance*** application scenario, where a BCI device enhances natural CNS output (e.g. a person using a BCI to monitor attention level during a demanding task). Here, nearly all identified application groups in Table 2 could be considered. Similarly, though more futuristic, the ***supplement*** application scenario, where a BCI device supplements natural CNS output (e.g. a person who is using a BCI to control a third robotic arm and hand) would mostly be suitable for *AT & Smart home control*, *Safety & Security* and *Entertainment & Gaming* market applications. Finally, the fact of using a BCI as a ***research*** tool can give rise to more novel market applications not identified so far.

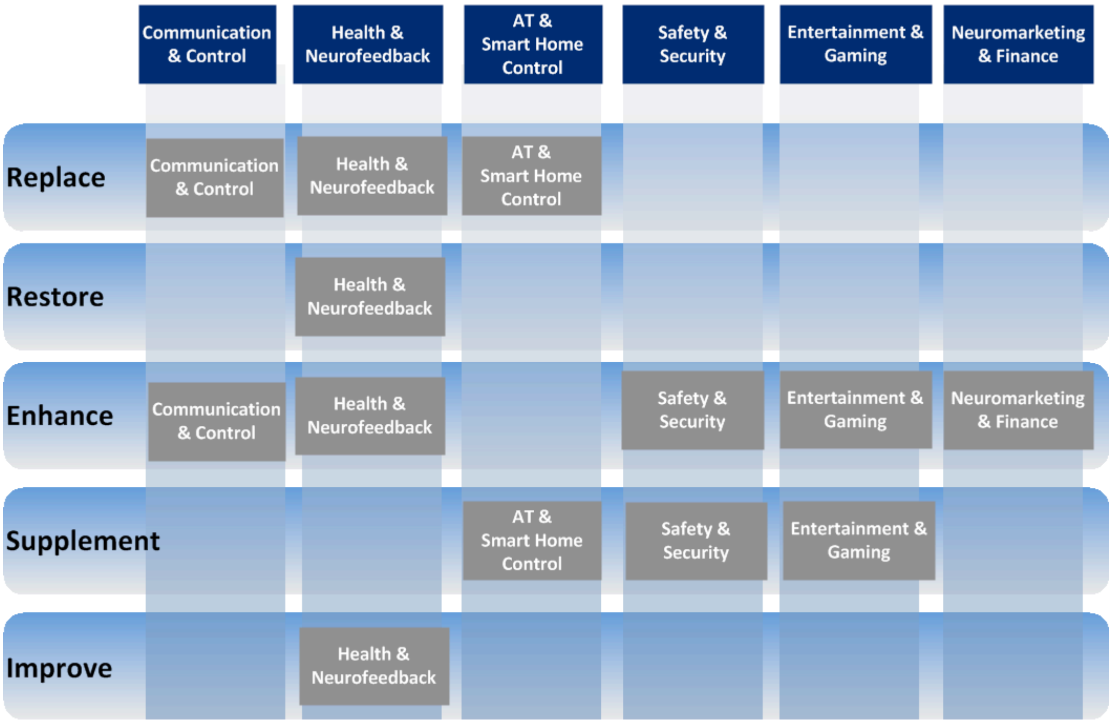

Figure 1 – Key BCI market applications and their relation to the BCI application scenarios.

4.4 Estimated market impact

Expanding into new markets offers even more growth opportunities than expanding into related markets. The further a company travels from its current markets, the greater the number of opportunities. However, it is also true that the further a company travels from what it knows, the greater are the risks. The difference between a related and an unrelated new market can be a matter of perspective, though. Based on the above identified key BCI market applications (see Table 2), we intend to provide a qualitative market analysis estimating their relative market growth and relative market value by 2020 (see Figure 2). This is also an approach to qualitatively assess potential future market opportunities for small-to-medium enterprises (SMEs) and other type of industry stakeholders in the BCI and related emerging markets. The estimated relative market growth and relative market value analysis portrayed in Figure 2 is based on our perspectives from the secondary input data gathered in the BNCI Industry Ecosystem Database, and the interpretation and experience of BNCI Horizon 2020 consortia experts (see Annex 2). This is obviously not exact science, but it might be used as a basis for the final roadmap.

The intensive competition in *Communication & Control* technologies, such as eye-tracking and enabling software, may slow down the growth of this conventional and most specific BCI field - but just relative to other new emerging applications groups - as illustrated in Figure 2.

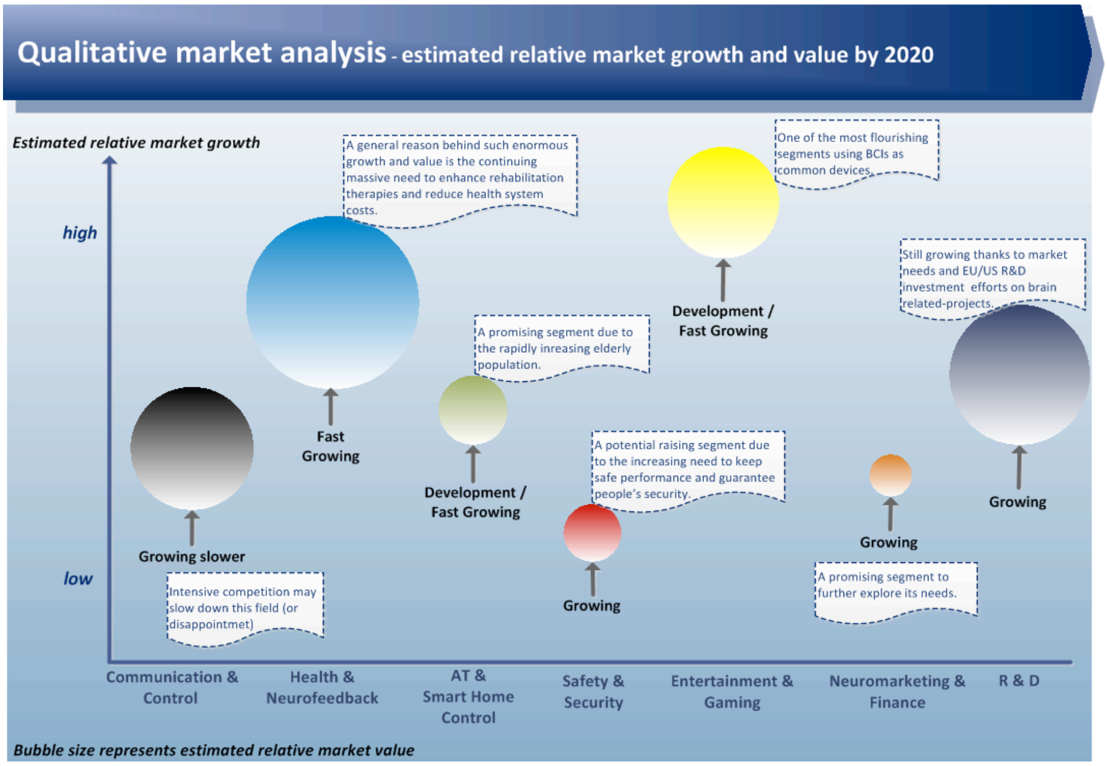

Figure 2 – Qualitative market analysis on estimated relative market growth and relative market value by 2020 from the identified key BCI market applications groups.

In *Health & Neurofeedback* related market applications, a general reason behind such enormous growth is the continuing massive need to enhance rehabilitation therapies, and preventive practices (for example to delay cognitive impairment) in an effort to reduce overall health care system's costs. The increase in life expectancy in developing countries, and the rapidly growing elderly population, especially in Western Europe and the US, will give rise to larger market opportunities in related fields in the upcoming years. Age is directly associated with stroke and dementia incidence, with age being an uncontrollable risk factor. This demographic change in the 21st century demands new strategies in health care addressed to the elderly. This framework makes health systems policies having to face several challenges concerning care for the elderly and comorbidities associated with old age. In the same line, new BCI solutions can emerge as *AT & Smart home control* applications, thus growing faster and in parallel with *Health & Neurofeedback* related applications by the year 2020. This assumption is based on the idea, that rehabilitation does not need to restrict itself to the hospital, but could also take place at the patient’s home. Of course, BCIs for rehabilitation and BCIs for AT are two different approaches. However, if end users get used to BCI devices "for rehab at home", this can open a window to use the same BCI device as a new way to generally access environment. Given the right measures, BCIs can therefore be easily extrapolated to different purposes and applications in manifold settings.

On the other hand, *Safety & Security* market applications are now a real emerging segment due to the increasing need to guarantee people's security and safety in diverse environments (see Table 2). *Entertainment & Gaming* applications are among the most flourishing segments using BCIs as common devices. Essential for its success are the availability and reduced costs of BCI gaming products. That is the reason why its estimated relative market value might be smaller in comparison to other BCI market applications. Further, *Entertainment & Gaming* applications may turn BCI shortcomings into challenges finding potential new end users. This fact may become an incentive for future industry investments that may lead to the highest estimated relative market growth (see Figure 2) for this application group. Likewise, but not yet with such a growth, neuromarketing and finance applications may be quite promising. BCIs may help to further explore consumer needs and even influence (IT)-finance, as a whole. Finally, *R & D* investment efforts are still required to try to answer basic science questions aiming to improve real-time processing methods and self-learning algorithms, to increase throughput rates, and to achieve higher accuracy and reliability.

5 Conclusion and future steps to roadmap

This deliverable sketched the evolution of the BCI industry towards the year 2020, and forms the basis to further evaluate different use case scenarios from the point of view of different industry stakeholders. We summarised emerging tools, technologies, and synergy fields with regard to their potential transfer to industry and their market impact. Further, we highlighted current and new target user groups, BCI application scenarios and the need for user involvement in the development process. Finally, we estimated the relative market growth and relative market value of a set of identified key BCI market applications by 2020, which are likely to guide future opportunities for interfacing with industry stakeholders, target end users, potential competitors, collaborators, and some of their interrelations. For the final roadmap, we intend to develop practical guidelines and actionable recommendations plans in relation to the selected use cases, as a tool mainly to SMEs and policy makers, in order to support and promote industry innovation.

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Annex 1: Classification matrix for BCI users and application scenarios

			Scenarios: Replace	Restore	Enhance	Supplement	Improve	Research
		Function of BCI	Assistive product (Communication, Interaction with the environment)	Prosthesis, Orthosis, Exoskeletons	Alert monitoring, neurofeedback to relax	Extra effector	Rehabilitation tool	Conditioning paradigm, Investigation of human brain functions
Users	**Primary Users**	**End users**	Persons with functional deficits	Persons with functional deficits needing prostheses	Healthy people[14] performing demanding tasks, gamers	Healthy people[15] performing tasks in extreme environments	Persons with functional deficits that can be improved	Researchers
Users	**Secondary Users**	**Non-Professional Users**	Family, Caregivers, Persons interacting with the user	Caregivers, Persons interacting with the user	Persons benefiting from the user's performance	Persons benefiting from the user's performance	Family, Caregivers, Persons interacting with the user	Persons benefiting from research results
Users	**Secondary/Tertiary Users**	**Professional users**	Manufacturers, AT professionals, IT managers, Researchers	Manufacturers, AT professionals, IT managers, surgeons, other MDs	Industry benefiting from the user's performance, military institutions	Industry benefiting from the user's performance, military institutions	Therapists, Medical doctors, Researchers	Researchers, Academics, Companies
Users	**Secondary/Tertiary Users**	**Other stakeholders**	Insurances, Public health system	Insurances, Public health system	Manufacturers	Manufacturers	Insurances, Public health system, Industry	Funding agencies, Publishers

[14] People with functional deficits can also take advantage of the Enhance scenario.
[15] People with functional deficits can also take advantage of the Supplement scenario.

Annex 2: Retreat surveys on application scenarios

The following survey was distributed among the industrial attendees in the BNCI Horizon 2020 Retreat in Hallstatt. There was a specific survey per discussion session matching each of the six BCI application scenarios. The content of the responses that were delivered back to us went into the analysis of the estimated market impact in relation to identified BCI application groups in section 4.4.

Replace Scenario - WP3 Industry

Please complete the following questions for each chapter.

1. Future user groups - Replace

Evaluate the following matrix

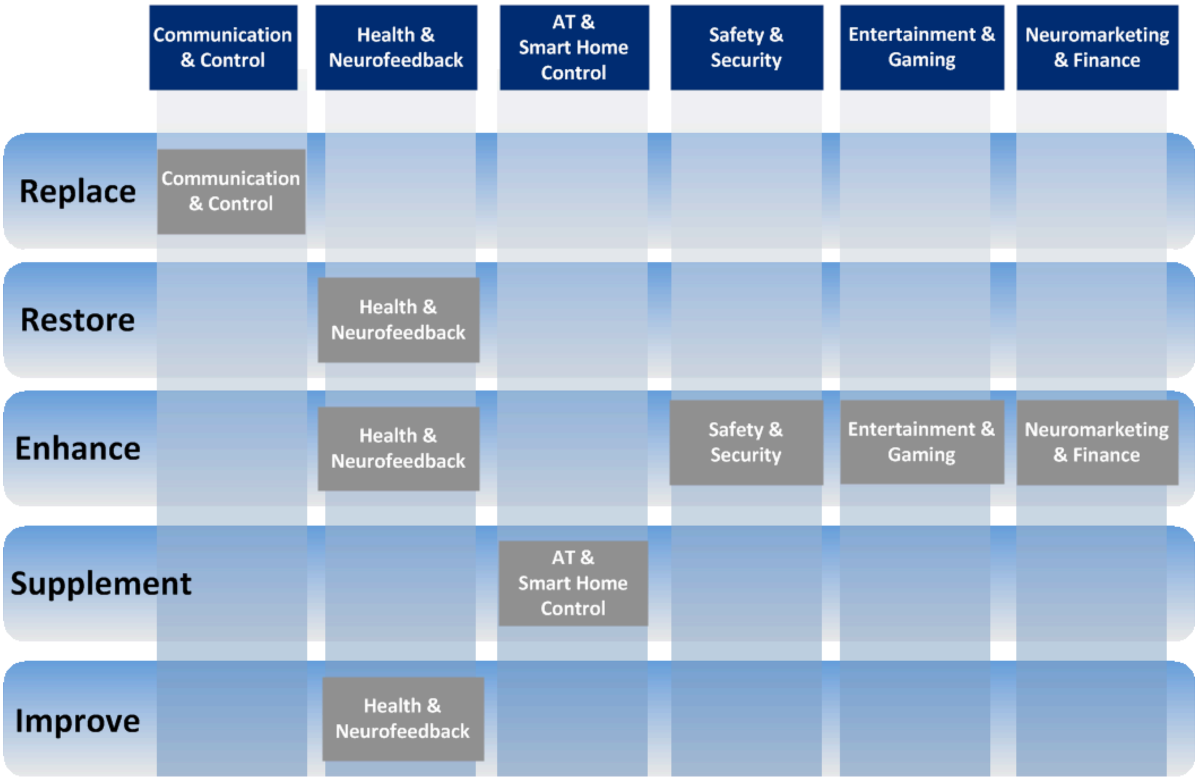
	Healthy	Patients	Disabled	Caregivers	Professionals	Health system
Replace			Disabled		Professionals	Health system
Restore		Patients	Disabled		Professionals	Health system
Enhance	Healthy			Caregivers	Professionals	
Supplement		Patients	Disabled	Caregivers		Health system
Improve		Patients			Professionals	Health system

Questions:

1. Do you agree on the identified future key user groups in the Replace scenario? What would you change?
2. Which are the specific target end users?
3. What do they need?
4. Which types of current (or improved) BNCI products may solve their problem? (specify system/device characteristics)
5. What are the advantages of using this product?
6. How much effort should they invest to use this product?
7. Why not another technology?
8. When and how should these end users be involved in the "development process" of a new product for this specific scenario?
9. What about ethics?

2. Key BNCI applications - Replace

Evaluate the following matrix

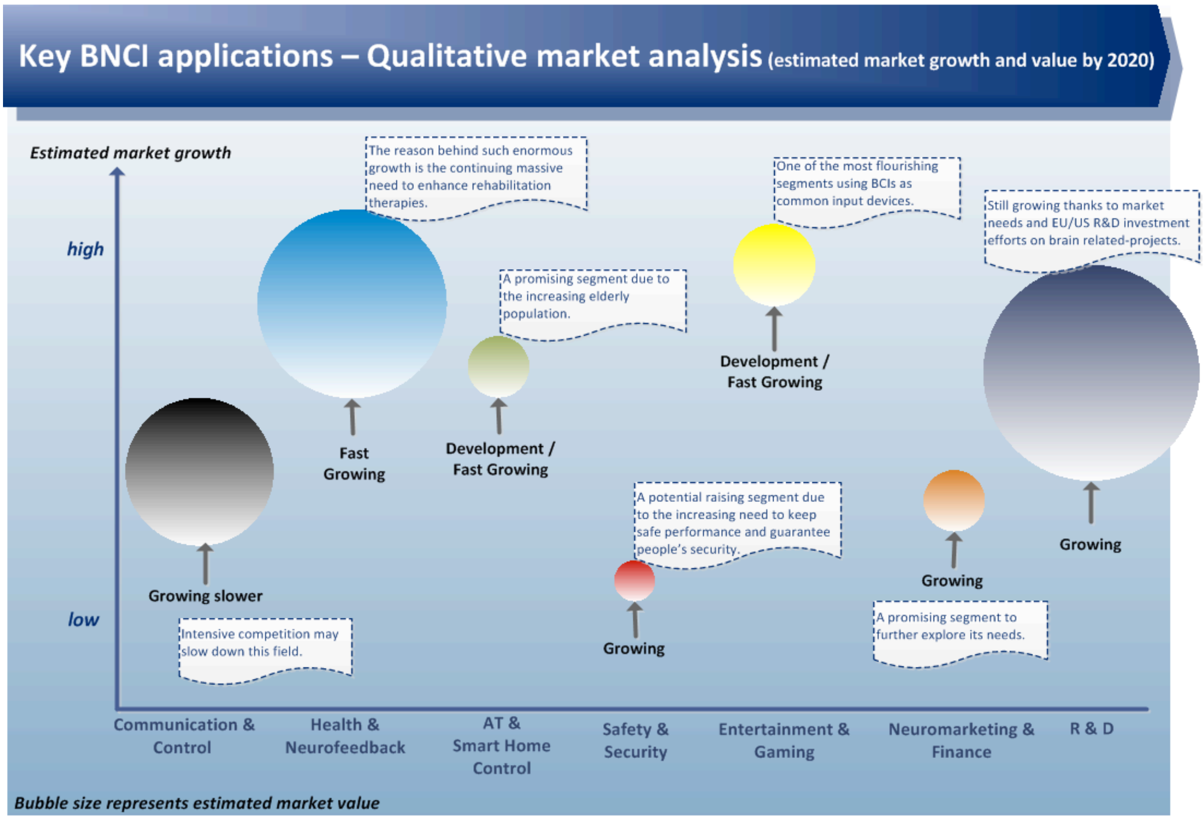


Questions:

1. Do you agree on the identified key application groups in the Replace scenario? What would you change?
2. Could you suggest more specific BNCI applications & technologies?
3. Which is their target market? (segments rel. related to 1a)
4. Which applications-scenarios will be sooner adopted by the industry? Why?
5. How big will be their potential market value?
6. How high will be their potential market growth?
7. Which measures are required to reinforce other applications-scenarios with less market value?

3. Market impact evaluation Replace (related to 2.)

Evaluate the market impact for the application group in relation to Replace Scenario



4. Potential R&D transfer to industry – Replace

Questions:

1. Which are the industry motivations & needs?
2. Which is the major bottleneck to develop products for this scenario (and related applications)?
3. Which may be the required R&D tools & techs to develop products for this scenario (and related applications)?
4. Can you describe potential success stories or business cases for this scenario?
5. Can you explicit feedback mechanisms between industry and academia?
6. What should policy makers do to reinforce R&D development in this scenario?